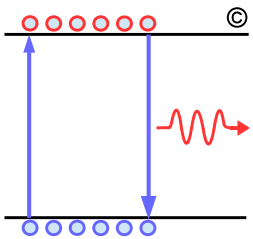

Evolution of 400 GbE PMD and Signaling

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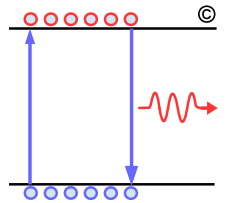
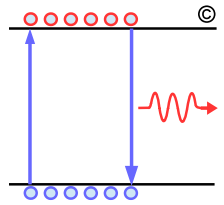
January 2014 Interim

Overview



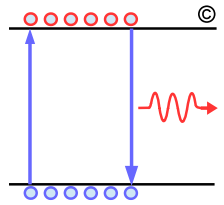
- Current objective review
- Possible evolution of 400 GbE PMDs
- Should we be defining CDAUI-8
- What we learned in the 802.3bm Higher Order Modulation (HOM) study
- Notable advancement

Current HSSG Objective Per Dallas Meeting



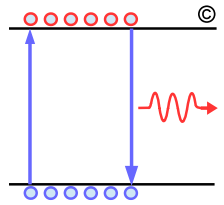
- **Provide physical layer specifications which support link distances of at least 100 m over MMF**
- **Provide physical layer specifications which support link distances of at least 500 m over SMF**
- **Provide physical layer specifications which support link distances of 2 km on SMF**
- **Provide physical layer specifications which support link distances of at least 10 km over SMF**
- **Key questions consensus need to be developed are:**
  - Do we define in this project more efficient PMDs
  - Do we define higher bit rate narrower CDAUI interface
  - At least out of Dallas meeting there was not enough reasons to define 400 GbE backplane objective at this time.

Possible Evolution of 400 GbE PMDs



- **Even reusing what is already defined in 802.3ba/bm still require a new clause**
  - Bundling and reusing existing 16xby 1st generation PMDs could enable some early adopters
  - But 1st generation PMDs due to cost and density will be short lived just like XSBI
- **The industry and IEEE need to focus on 2nd generation PMDs to deliver lower cost and more efficient 400 GbE**
  - To deliver cost and density the 2nd generation PMDs require CDAUI-8 based on 50 Gb/s signaling
  - An interface base on CDAUI-16 will ~double current CFP2 module width from 41.5 mm
  - CDAUI-4 and PMDs based on 100 Gb/s signaling may need to wait for the next project.

Possible Evolution of 400 GbE PMDs Cont.

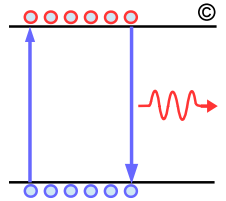


- 1st generation 400 GbE is reuse will be based on NRZ
- 2nd generation PMDs will be more efficient and may use some form of HOM
- 3rd generation likely will take too long to define in this project

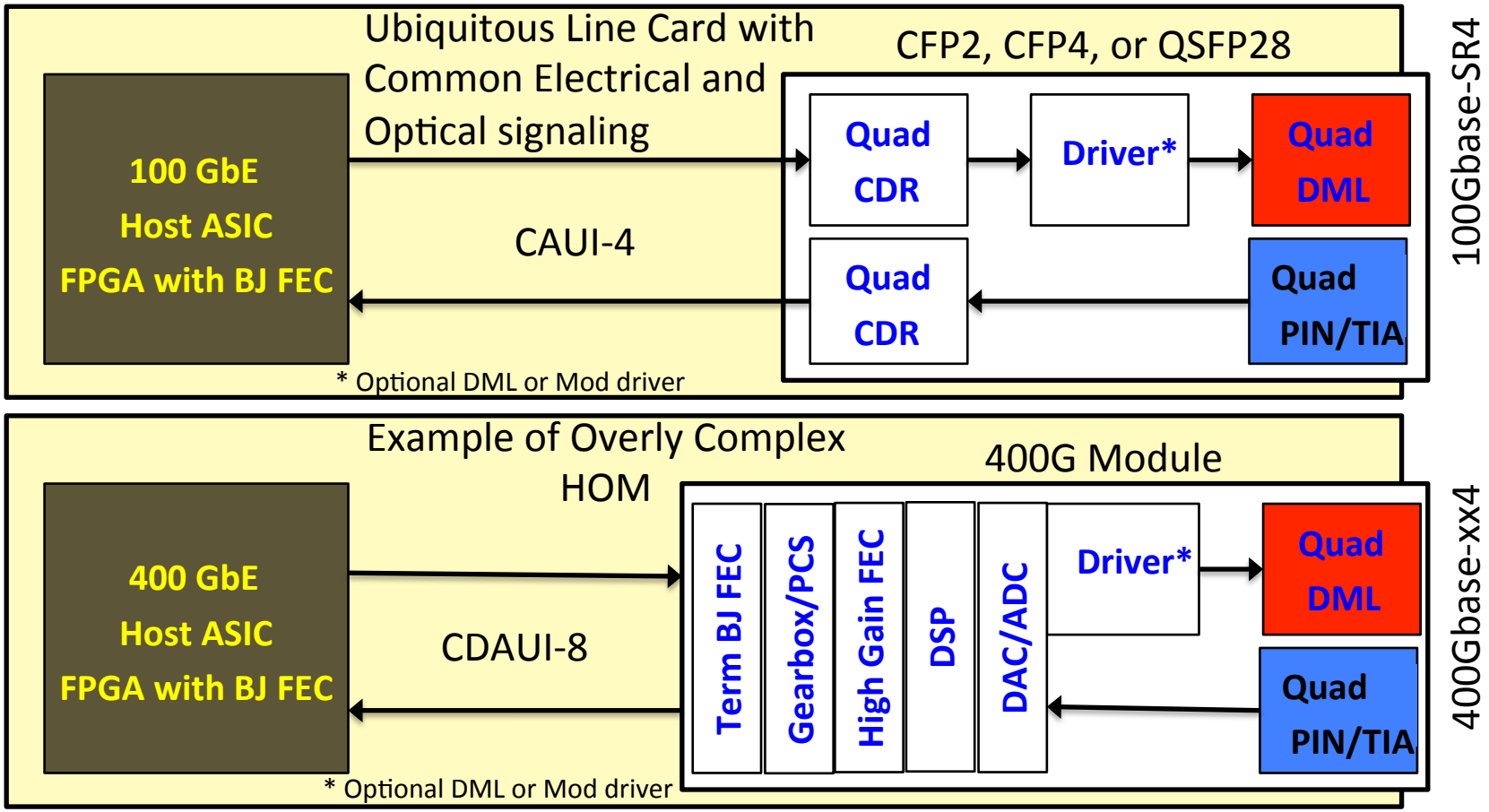
PMD	Gen 1 (25 Gb/s/ lane)	Gen 2 (50 Gb/s/ lane)#	Gen 3 (100 Gb/s/ lane)#
CDAUI	CADUI-16	CADUI-8	CADUI-4
100 m MMF	SR-16	SR-8	SR-8+WDM*
500 m SMF	PSM-16	PSM-8, WDM-8	PSM-4 or WDM-4
2 km SMF	NA	WDM-8	WDM-4
10 km SMF	PSM-4+(100G-LR4)	WDM-8	WDM-4

 # Some form of HOM (Higher order modulation is an option)
*** WDM in case of MMF could mean 100+ nm spacing and in case of SMF could mean 100's GHz spacing**

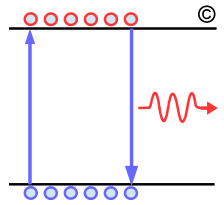
Today 100 GbE PMD Architecture



- **100 GbE based on NRZ is ubiquitous interface allowing simple pass through**
  - Can we create a ubiquitous interface with HOM having common FEC and signaling for chip to module and optics?

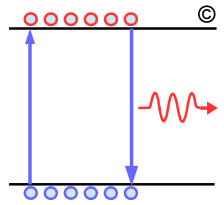


What We Learned from 802.3bm HOM Investigation



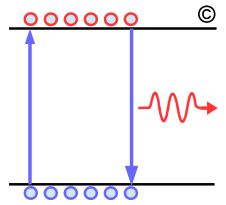
- **802.3bm sowed the seed that HOM is possible option for short reach (500 m) data center interconnect and brought to realization many pitfalls of HOM with optical signaling**
  - 802.3bm task force has many valuable contributions http://www.ieee802.org/3/bm/public/index.html
  - High order PAM >PAM-4 is not a practical option for optics due to RIN and MPI
  - While the promoter of PAM fighting in world war I type trenches were trying to solve high order PAM (PAM-12/16) issues DMT emerged as an alternative signaling with lower optical penalty and requiring less excess BW but with its own set of issue
    - DMT has penalty associated with peak to average power and extra latency associated with FFT bins size
- **As we develop the 2nd and 3rd generation 400 GbE PMDs HOM and WDM need to be part of the equation**
  - But we need to expand our horizon beyond just studying PAM and DMT.

Notable Key Advancement to Enable Next Generation PMDs



- 56.1 Gb/s NRZ Modulated 850 nm VCSEL-Based Optical Link, D. M. Kuchta et al., OW1B.5, OFC 2013
  - With only transmit FFE
- Toward 400Gbase 4 lane Solution Direct Detection of MultiCap Signal in 14 GHz Bandwidth per Lane, Migue Iglesias Olmedo et al., Post Deadline, OFC 2013
  - A DML with only 14 GHz was able to operate at 100 Gbps
  - Dispersion penalty between 2 km and 10 km was negligible
- Integrated Silicon Photonic Laser Sources for Telecom and Datacom, Brian R. Koch et al., Post deadline, OFC 2013
  - A 16 channel L-band 200 GHz spacing WDM transmitter
- We will likely see more fundamental advancements on HOM and NRZ at OFC 2014 in March
- PAM and DMT investigated in detail in 802.3bm are part of the equation as well.

Summary



- **HSG objective for PMD reaches of 100 m, 500 m, 2 km, and 10 km can be met based on todays available and emerging technology**
  - Due to limited time the project scope may need to be limit and we may not have sufficient time to develop the most efficient highest bit rate PMD in this project
  - With several possible solution for each PMD implementation we need to consider cost, power, and latency to determine the best solution
    - Higher Buadrate NRZ, WDM, HOM, and parallel fiber all need to be considered as part of the solution set
- **To enable 2nd generation PMDs we need to add an objective CDAUI-8 to enable CFP-2 type module for 400 GbE**
  - CADUI-8 can enable module to operate as pass through if the electrical and optical signaling are the same
- **A key goal for development of 2nd and 3rd generation PMDs is maintaining ubiquitous electrical and optical signaling ideally for all PMDs.**